ANALYZING FASTNESS OF COTTON DYED WITH ARECANUT EXTRACT AND NATURAL MORDANTS - AN ECO- FRIENDLY APPROACH

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Abstract

The increasing environmental concerns associated with synthetic dyes and chemical mordants have shifted attention toward eco-friendly alternatives in the textile industry. This study investigates the dyeing of cotton fabrics using arecanut (Areca catechu) extract as a natural dye, coupled with natural mordants, to assess the fastness properties and environmental sustainability of the process. Arecanut, a readily available agricultural byproduct, was selected for its high tannin content, which imparts natural color to textiles. Natural mordants, including alum, tannic acid, and bio-sourced metallic salts, were used to enhance dye uptake and fastness properties such as wash, rub, and light fastness. The dyed fabrics were subjected to standard testing procedures to evaluate these properties. Additionally, the process was assessed for its environmental impact by analyzing effluent quality. The results demonstrated that the use of natural mordants significantly improved the fastness properties of arecanut-dyed cotton, making it a viable and sustainable alternative to synthetic dyeing processes. This study highlights the potential of integrating natural dyes and mordants in the textile industry, offering an eco-friendly approach to fabric dyeing that aligns with sustainable development goals.

Keywords

Natural Dye, Arecanut, cotton, mordant, Eco-friendly, fastness properties, pomegranate rind, turmeric, myrobolan.

1. INTRODUCTION

The processing of textile is one of the most polluting events on earth. Making just a T-shirt needs around 250 gallons of water from raw to end position. The waste from dyeing carries thousands of pollutants and chemicals dumped into rivers and cannels near by. [1]That's why we should step forward for eco-friendly processing and use eco-friendly chemicals as well. Using natural dyes in the coloration process of textile can be a step towards a new era of less polluting processing of textile. All new trend for fashion and textile is green and eco-friendly textile. [2] All fashion brands are now stepping forward for making the world less polluted and more livable.

Thus the use of environment friendly, bio degradable, non – toxic, less – polluting natural dye is increasing day by day in various sectors. The UV absorption property of most of the natural dyes makes it safer from harmful UV of sun light. Foods, drugs, cosmetics and textiles are the main market for natural dyes. [3]Some drawbacks of using natural dye may present as poor fastness property, research is going on to get rid of this.

Natural dyes are classified into two types substantive dyes and adjective dyes. Substantive dyes are the dyes that react with the fibre directly(indigo, turmeric).Adjective dyes(logwood, madder) are mordanted with metallic salts.[4]In the present work, locally available crushed arecanut were soaked in warm water overnight and the extract was taken by boiling the arecanut in same water. It's used to dye cotton fabric using combination of mordants simultaneously and The fastness properties was tested to evaluate the dyed samples.[5,6]

2. MATERIAL AND METHODS

2.1 Materials

Raw material: Cotton, Arecanut, Pomegranate rind, turmeric, myrobolan

Figure 1: Arecanut Figure 2: Arecanut extraction

Figure 3: Mordants Figure 4: Individual mordants on bath

Arecanut:

- Natural dyes have gained renewed interest in the textile industry due to growing environmental concerns and the need for sustainable alternatives to synthetic dyes.
- Among the various natural sources, arecanut (Areca catechu)-commonly known as betel nut-has emerged as a promising natural dye owing to its content of phenols and tannins.[7]
- Arecanut is traditionally used in cultural and medical applications, but recent studies have demonstrated its potential as a dye for textile fibres such as cotton, silk and wool.[8]
- The extract from arecanut exhibits good affinity to fabrics and can produce shades ranging from light brown to deep reddish brown,depending on mordants and pH levels used during dyeing process. [9]

Pomegranate rind:

- Pomegranate is a fruit that contains 25% natural tannin. The rind of the fruit is used for the deepest yellow color.A yellow dye is also present which can be used to dye wool,silk and cotton with good fastness properties. [10,11]
- Pomegranate is an aromatic dye that yields an especially nice green-yellow color. The age of the fruit affects the color of the dye: the less ripe the fruit, the greener the yellow. Pomegranate has a high tannin content which when combined with iron gives a yummy deep moss green.[12,13]

Myrobolan:

- Myrobolan acts as a bio-mordant, enhancing the binding of natural dyes to fabric fibers without the need for harmful metal salts like alum or copper sulfate. The presence of hydrolyzable tannins, particularly chebulinic and gallic acid derivatives, gives it strong astringent and fixative properties, making it especially effective on protein (silk, wool) and cellulose (cotton) fibers. When used as a pre-mordant or combined mordant, Myrobolan improves color depth, brightness, and fastness of the dye. [14]

- The increasing demand for eco-friendly and sustainable practices in the textile industry has led to renewed interest in **natural dyes and mordants.** One such valuable resource is **Myrobolan (Terminalia chebula),** a plant traditionally used in Ayurveda and known for its high **tannin** content. The dried fruit of Myrobolan yields a yellowish dye and has historically served as both a **colorant** and a **natural mordant** in textile dyeing.[15]

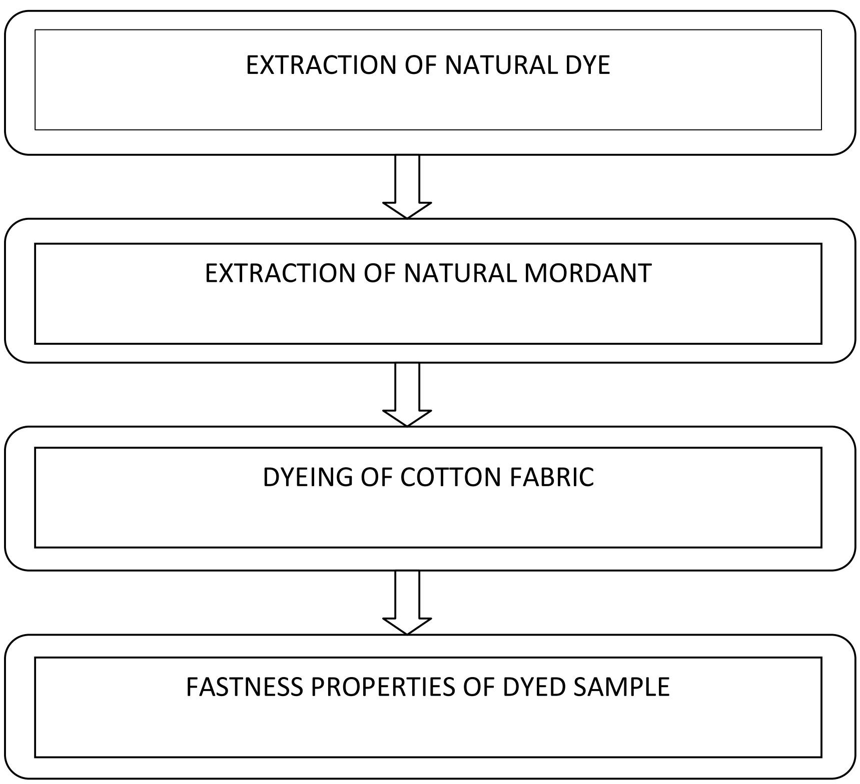
Turmeric:

- Natural dyeing has gained significant interest as a sustainable and eco-friendly alternative to synthetic dyes, particularly in the textile industry. Among the many plant-based sources, turmeric (Curcuma longa) stands out due to its vibrant yellow pigment and medicinal properties. The principal coloring component of turmeric is curcumin, a polyphenolic compound known for its bright color and strong affinity to natural fibers. [16]
- While turmeric is traditionally used as a dye, recent studies have shown its potential as a natural mordant as well. Due to its polyphenolic structure and antioxidant activity, turmeric can enhance the fixation of other natural dyes onto fabrics, especially when used in combination with or as a pre-treatment to the main dye. Its use eliminates the need for harmful metal-based mordants and contributes to a more environmentally friendly dyeing process.[17,18]

Table 1 : Fabric Particulates

Particulars	Cotton fabric
Fabric structure	Woven (Plain weave)
Ends/Inch	47.2
Picks/inch	36.2
Gsm	130
Yarn count	60s

2.2 Methods



Flow chart -1 : Methodology [6,5]

2.2.1 Preparation of Raw Material

Powdered raw material (pomegranate rind, turmeric, myrobolan)

⇩

Soaking in water for 12 hours

⇩

Boiling at simmering point (90-92^{o}C) for 30 mints to 1 hour

⇩

Filteration

⇩

Extraction of mordant [2,6]

2.2.2 Extraction of natural dye

The areca nuts were collected from the market. A known quantity of arecanut was soaked in warm water overnight. The arecanut extract was taken by boiling arecanut in same water.The pH was changed to alkaline media(Ph-10) by potassium hydroxide while extracting dye. Finally the dye extract was allowed to cool, filtered and used for dyeing. [4,2]

2.3 Process Parameter

Parameters for dyeing [6,2]

- Material : liquor ratio - 1:30
- Temperature - 90-100^{o} C
- Time - 45 mints

2.4 Mordanting and Dyeing Process [18,19,26]

- Sample 1: No mordant
- Sample 2: Arecanut dye and Pomegranate rind mordant
- Sample 3: Arecanut dye and Turmeric mordant

- Sample4:Arecanut dye and Myrobolon mordant

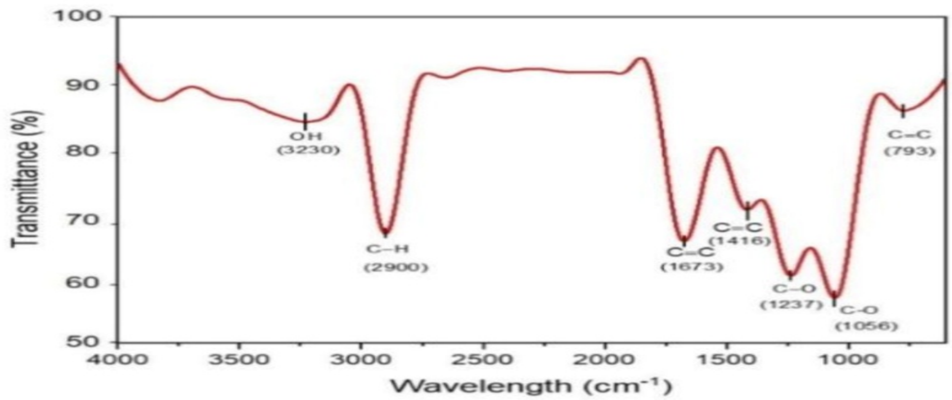
2.5 Testing Methods

The following tests were conducted as per ISO standards

- Wash fastness (ISO 105 C06) [20]
- Rubbing fastness (ISO 105 X12) [20]
- Perspiration fastness (ISO 105 E04) [21]
- Water fastness (ISO 105 E01) [21]
- Pilling resistance, pH, bursting strength, water absorbency

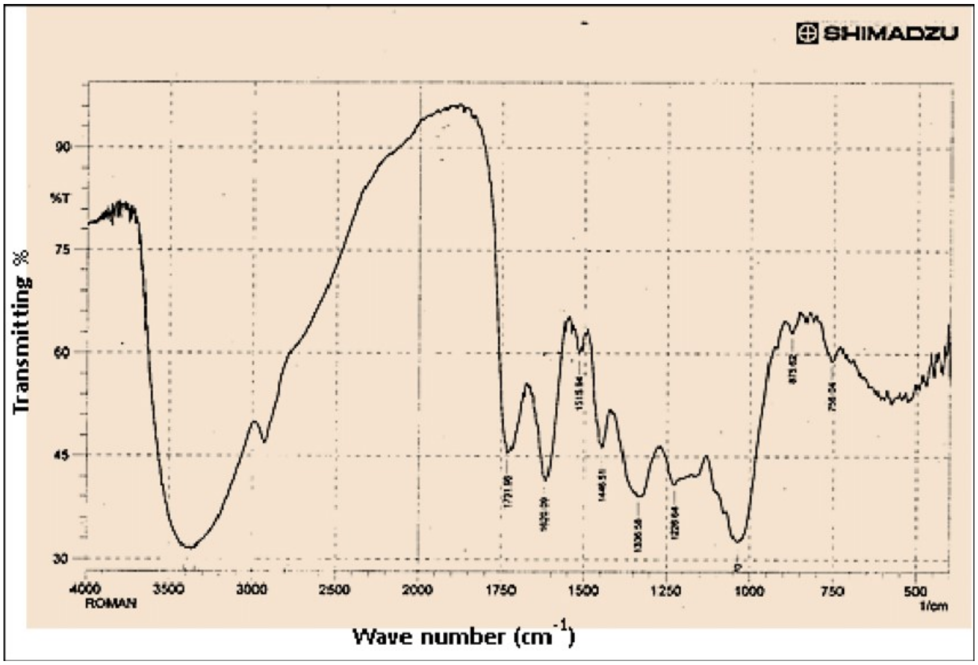
3. RESULT AND DISCUSSION

Fourier – Transformed infrared spectroscopy (FTIR) analysis: Arecanut [22]



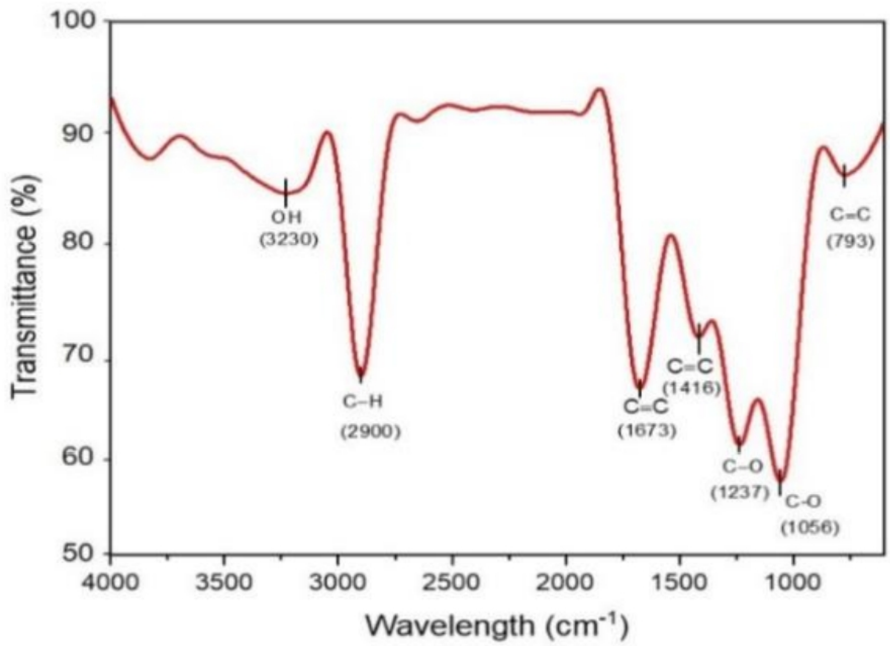
Wavenumber (cm⁻¹)	Functional Group	Possible Compounds	Interpretation
~3400–3200	–OH stretching (broad)	Phenols, alcohols, flavonoids	Indicates hydrogen bonding; common in polyphenols
~2920–2850	C–H stretching (aliphatic)	Fatty acids, hydrocarbons	Presence of CH_2 and CH_3 groups
~1730–1700	C=O stretching (esters, acids)	Carboxylic acids, esters	Likely from tannins or fatty acids
~1650–1600	C=C/C=O stretching (aromatic or amide)	Flavonoids, alkaloids, proteins	Aromatic ring or amide presence
~1510–1450	Aromatic C=C stretching	Phenolic compounds	Confirms aromatic rings (e.g., catechins)
~1400–1380	C–H bending	Bending	CH_3 bending vibrations

Fourier – Transformed infrared spectroscopy (FTIR) analysis: Pomegranate rind [23]



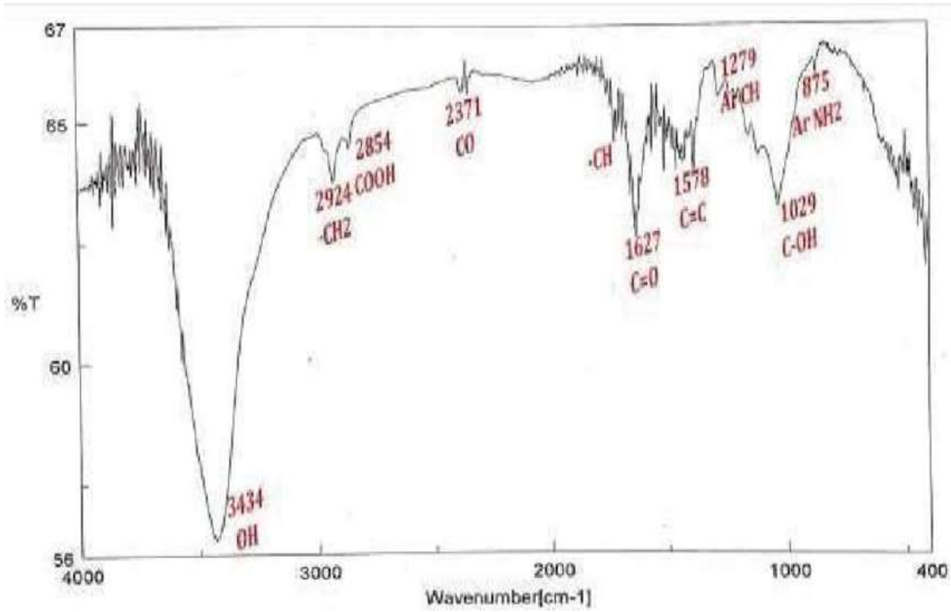
Wavenumber (cm⁻¹)	Functional Group	Type of Vibration	Possible Compounds
3400–3200	O–H (hydroxyl)	Broad stretching	Phenols, alcohols (e.g., gallic acid, tannins)
2930–2850	C–H (aliphatic)	Stretching	CH_2/CH_3 in organic acids or flavonoids
1715–1680	C=O (carbonyl)	Stretching	Carboxylic acids, esters (e.g., gallic acid)
1610–1580	C=C (aromatic) or C=O (amide I)	Stretching	Aromatic rings, ellagitannins
1450–1410	C–H bending (methyl/methylene)	Deformation	Alkanes, substituted aromatics
1320–1250	C–O (phenolic or carboxylic)	Stretching	Phenolic acids (gallic/ellagic acid)
1200–1000	C–O–C / C–OH	Stretching	Polysaccharides, polyphenols
880–650	C–H (aromatic out-of-plane)	Bending	Substituted benzene rings

Fourier – Transformed infrared spectroscopy (FTIR) analysis: Myrobolan [24]



Wavenumber (cm^{-1})	Functional Group	Type of Vibration	Associated Compounds
3400–3200	O–H (hydroxyl group)	Broad stretching	Phenols, tannins, alcohols (e.g., gallic acid)
2920–2850	C–H (aliphatic)	Stretching	Aliphatic chains in polyphenols
1720–1700	C=O (carbonyl group)	Stretching	Carboxylic acids, esters (e.g., gallic acid)
1620–1580	C=C (aromatic) or C=O (amide I)	Stretching	Aromatic rings, ellagitannins, flavonoids
1450–1410	C–H (methyl/methylene)	Bending	CH_2/CH_3 groups in organic compounds
1310–1240	C–O (phenolic or carboxylic)	Stretching	Tannins, polyphenolic acids
1200–1020	C–O–C / C–OH	Stretching	Sugars, polyols, tannin derivatives
850–650	Aromatic C–H out-of-plane	Bending	Substituted aromatic rings

Fourier – Transformed infrared spectroscopy (FTIR) analysis: Turmeric [25]



Wavenumber (cm⁻¹)	Functional Group	Type of Vibration	Associated Compounds
3500–3200	O–H (hydroxyl group)	Broad stretching	Phenolic –OH groups in curcumin
3000–2850	C–H (aliphatic)	Stretching	Methyl and methylene groups
1625–1600	C=O and C=C (conjugated ketone)	Stretching	Conjugated diketone group in curcumin
1510–1450	C=C (aromatic ring)	Stretching	Aromatic rings in curcuminoids
1430–1370	C–H bending (methyl group)	Bending	CH_3 bending vibrations
1270–1210	C–O (phenol or ether)	Stretching	Phenolic or methoxy groups
1150–1020	C–O–C / C–OH	Stretching	Ether and alcohol groups
890–650	Aromatic C–H (out-of-plane)	Bending	Aromatic substitution patterns

1. Arecanut Extract Dye (Alone)

Wash Fastness 2–3 (moderate) Arecanut contains tannins and polyphenols but has moderate substantivity to cotton.
Rubbing Fastness Dry: 3–4, Wet: 2–3 Slight surface dyeing results in some loss on rubbing.
Perspiration Fastness Acidic: 3, Alkaline: 2–3 Tannins can be affected by alkaline sweat.
Main chemical components Tannins, polyphenols These give moderate binding to cellulosic fibres.

2. Arecanut + Turmeric

Wash Fastness 3 (moderate) Turmeric (curcumin) is not very wash-fast; dye tends to bleed.
Rubbing Fastness Dry: 2–3, Wet: 2 Turmeric has poor rubbing fastness; arecanut moderates it slightly.
Perspiration Fastness Acidic: 3, Alkaline: 2 Curcumin is pH-sensitive, especially in alkaline sweat.

Main chemical components Tannins (Arecanut) + Curcumin (Turmeric) is bright but unstable; needs better fixation.

3. Arecanut + Pomegranate Rind

Wash Fastness 3–4 (good) both contain tannins, improving fixation.
Rubbing Fastness Dry: 4, Wet: 3–4 High levels of tannins lead to better surface binding.
Perspiration Fastness Acidic: 4, Alkaline: 3–4 Stable against perspiration; less color change.
Main chemical components : Tannins Strong affinity to cellulose; improved depth and fixation.

4. Arecanut + Myrobolan (optional addition)

Wash Fastness 3–4 Myrobolan acts as a natural mordant (tannins).
Rubbing Fastness Dry: 4, Wet: 3–4 Better fixation on fibre; smooth feel.
Perspiration Fastness Acidic: 4, Alkaline: 3–4 Tannins resist acid/alkali sweat.
Chemical properties Gallic acid, ellagic acid, tannins Help improve colour depth and fastness.

The dyed samples are analysed for various fastness properties and their values are tabulated

Test Parameter	Arecanut Dye Only	Arecanut Dye + Turmeric Mordant	Arecanut Dye + Pomegranate Mordant	Arecanut Dye + Myrobolon Mordant
Wash Fastness	2-3	3	4	4
Rubbing(Dry)	3-4	2-3	4	4
Rubbing(Wet)	2 -3	2	3-4	3-4
Perspiration(Acid)	3	3	4	4
Perspiration(Alkali)	2-3	3	3-4	4
Water Fastness	3	4	4	4
Bursting Strength(kPa)	240	245	250	255
Ph	6.8	6.7	6.9	6.8
Pilling Grade	3	3	3	3 - 4
Absorbency	Good	Good	Good	Very Good

The fastness properties and physical characteristics of cotton fabric dyed with arecanut extract, both individually and in combination with natural mordants (turmeric, pomegranate rind, and myrobolan), were assessed using standard textile testing procedures. The results are detailed in above table.

1. Wash Fastness

The wash fastness of fabric dyed with arecanut extract alone recorded a moderate rating of 2–3, indicating slight to moderate fading. However, the use of natural mordants significantly improved the wash fastness, especially with pomegranate and myrobolan mordants, both achieving a grade of 4, indicating good fastness. This improvement can be attributed to stronger bonding between the dye and fiber facilitated by the natural mordants, especially tannin-rich ones like pomegranate and myrobolan .

2. Rubbing Fastness

For **dry rubbing**, arecanut dye alone showed a fastness of 3–4, which reduced slightly when turmeric was used (2–3). Both pomegranate and myrobolan mordants maintained a consistent rating of 4, showing enhanced pigment adherence. In **wet rubbing**, the control sample (arecanut only) and turmeric-mordanted samples showed lower resistance (2–3), while pomegranate and myrobolan again improved performance (3–4). This suggests that pomegranate and myrobolan create a more water-resistant dye-fiber interaction.

3. Perspiration Fastness (Acid & Alkali)

The samples showed moderate resistance to acid and alkaline perspiration when dyed with arecanut alone (2–3). Turmeric showed a similar performance, while pomegranate and myrobolan demonstrated superior fastness values (up to grade 4), highlighting their capacity to form stable dye complexes under varied pH conditions commonly encountered in perspiration.

4. Water Fastness

Water fastness increased from grade 3 (arecanut alone) to grade 4 with all mordants. This shows a clear improvement in dye retention and reduced bleeding, again supporting the effectiveness of tannin-rich natural mordants in enhancing dye fixation.

5. Bursting Strength

Bursting strength values showed a slight increase from 240 kPa (arecanut only) to 245, 250, and 255 kPa for turmeric, pomegranate, and myrobolan, respectively. These increments suggest that mordanting not only enhances dye binding but may also affect fabric structure, possibly through swelling or cross-linking effects induced by bioactive compounds in the mordants.

6. pH

All samples maintained a near-neutral pH, ranging between 6.7 and 6.9, which is desirable for skin contact textiles. This also confirms the mild and eco-friendly nature of the dyeing process employed.

7. Pilling Grade

Pilling grades remained consistent (grade 3) except for the myrobolan-treated sample, which scored slightly higher (3–4), indicating improved surface integrity. This may be due to the astringent properties of myrobolan that may tighten the fiber structure.

8. Absorbency

All samples except the myrobolan-mordanted fabric demonstrated "Good" absorbency. The fabric dyed with myrobolan showed “Very Good” absorbency, likely due to better fabric swelling and mordant-fiber interaction, which may enhance hydrophilic character.

Fastness Comparison

All the dyes have well to very good fastness properties on average. Fastness varies mordant to mordant. In our review we have seen different mordant showed different behavior with dye. So mordant and type mordant are also factor fastness. But in many cases it has been seen that synthetic mordants works better to get more colour strength and fastness property than the natural one. The findings clearly establish the role of natural mordants in enhancing the fastness and performance characteristics of cotton dyed with arecanut extract. Among the tested mordants, myrobolan exhibited the best overall performance**,** followed closely by pomegranate rind, making them suitable eco-friendly alternatives to conventional chemical mordants in natural dyeing.

CONCLUSION

People are now more aware of sustainability and environment friendly products. As natural dye shows nontoxic, non-allergic effects and results in less pollution as well as fewer side effects, it becomes an important area in the field of textile dyeing research. On this paper different type of extraction method of natural dye and properties of the dyed fabrics has been discussed. As it is difficult to get many types of dyes together in one place, this paper will help the new researcher to get an idea about extraction methods and properties of dyed fabric in one place.

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